Heritage Science

RESEARCH

Open Access

An investigation of Bellini's *Transfiguration* in the Capodimonte museum by means of XRF and visible reflectance hyperspectral imaging: Bellini's handling of materials in the head and figure of the transfigured Christ

Laurence de Viguerie[1*], Helen Glanville[1], Marie Radepont[1], Angela Cerasuolo[2,3], Alessandra Rullo[2], Claudio Seccaroni[4] and Philippe Walter[1]

Abstract

The *Transfiguration* by Giovanni Bellini in the Museo di Capodimonte (Naples) is an iconic image of a transcendental event at the heart of the Christian religion. Using non-destructive chemical imaging, and focusing on the central image of the transfigured Christ we have studied by what means and with what materials the artist represented this divine event. The results showed what is to date the earliest use of the pigment stibnite. The techniques employed demonstrate both continuity with Bellini's earliest works (such as the combination of the use of shell-gold and organic, tinted layers), but also his knowledge of Netherlandish painting. This research has furthered our understanding of how he achieved the luminosity so characteristic of his translation of the divine into the materiality of paint.

Keywords Painting technique, Chemical imaging, MA-XRF, Visible reflectance hyperspectral imaging, Stibnite, Pigment mixtures

Introduction

« Under Bellini's brush the Transfiguration is realized as an event in which Christ literally mediates between the subtle air and dense matter, between the radiant heaven and the rock strata beneath the earth. (…) A sign of heavenly grace is the preeminent quality of colour in Bellini's autograph works.» [1]

How does Bellini achieve such an effect, translating a divine event—"There he was transfigured before them. His face shone like the sun, and his clothes became as white as the light. (Matthew 17: 2, Bible, new international version)"- into the materiality of his painting? To answer this question, a technical investigation of Giovanni Bellini's transcendental masterpiece, *The Transfiguration*, was carried out in the Capodimonte museum (Fig. 1). The *Transfiguration* is part of the cycle of the Glorification of Christ, together with the Resurrection and the Ascension, and represents not only the recognition of Jesus as Son of God, but also the continuity of the New Testament with the Old: the figure of Moses (to the left of Christ) stands for the Hebrew Law, and Elijah (to

*Correspondence:
Laurence de Viguerie
laurence.de_viguerie@sorbonne-universite.fr
[1] Laboratoire d'Archéologie Moléculaire et Structurale, LAMS, Sorbonne Université, CNRS, 4 pl. Jussieu, 75005 Paris, France
[2] Museo e Real Bosco di Capodimonte, via Miano 2, Naples, Italy
[3] Istituto di Scienze del Patrimonio Culturale ISPC, Consiglio Nazionale delle Ricerche CNR, Naples, Italy
[4] ENEA, Unità Tecnico Scientifica per i Materiali e le Nuove Tecnologie, C. R. Casaccia, s.p. Anguillarese 301, Santa Maria di Galeria, 00060 Rome, Italy

Fig. 1 *The Transfiguration* by Giovanni Bellini, 1478–1479, 115 × 152 cm^2, after its restoration in 2021, Capodimonte museum (Naples)

the right) for the Prophets. The figure of Christ, enveloped in the white draperies required by tradition, is presented in the *posa orante*—the pose characteristic of the Byzantine tradition—his arms outstretched, praying and receiving God's grace [2]. The painting was under restoration, being cleaned of its old oxidised varnishes, and retouching removed [3, 4]. We were thus asked to answer specific questions linked to the restoration process in addition to furthering our understanding of Bellini's materials and technique.[1]

Point XRF measurements as well as XRF and hyperspectral imaging techniques (which benefited particularly from the absence of reflectant varnish on the paint surface) were employed to this end. Although Bellini's technique has been studied in depth over the years [5–11], chemical imaging is a recent addition to the field [7] which enriches our understanding of Bellini's handling of the materials at his disposal. Comparative material—both published and unpublished—was provided by examinations of the works and scientific documentation at the National Gallery, London,[2] as well as articles in scientific publications and catalogues addressing the subject of Bellini's technique. We highlight here a number of points focusing on the head and draped figure of Christ which we investigated in greater detail.

Historical elements and provenance

The precise original location and commission of the work are not known, although likely hypotheses have been put forward ([3], p. 350). What is known with a degree of certainty are the dates of execution, thanks to the interpretation of the Hebrew inscriptions on the scrolls held by Moses and Elijah, who stand by the sides of the Transfigured Christ: the *Transfiguration* was painted after the year 5239 of the Hebrew calendar (September/October 1478 and October 1479). In those years, Giovanni Bellini (c. 1430–1516) was fully developing what would become the core characteristics of the Venetian style. The founding element was the unity of the figures with the landscape enveloped in light, which here plays a key role, at the same time natural and symbolic. The use of oil as a

[1] The restoration was preceded and accompanied by an articulated investigation campaign, to which, in addition to LAMS, Emmebi Diagnostica Artistica and ENEA contributed with the support of Intesa Sanpaolo; the results have so far only been partially published [4, 5] and a more comprehensive publication is being prepared.

[2] In February 2019, thanks to IPERION-ARCHLAB European funding, Angela Cerasuolo, Helen Glanville and Alessandra Rullo were able to consult the archival material in the Scientific Department, National Gallery, London and benefit from the expertise and discussions with Marika Spring, Jill Dunkerton, David Peggie and Rachel Billinge.

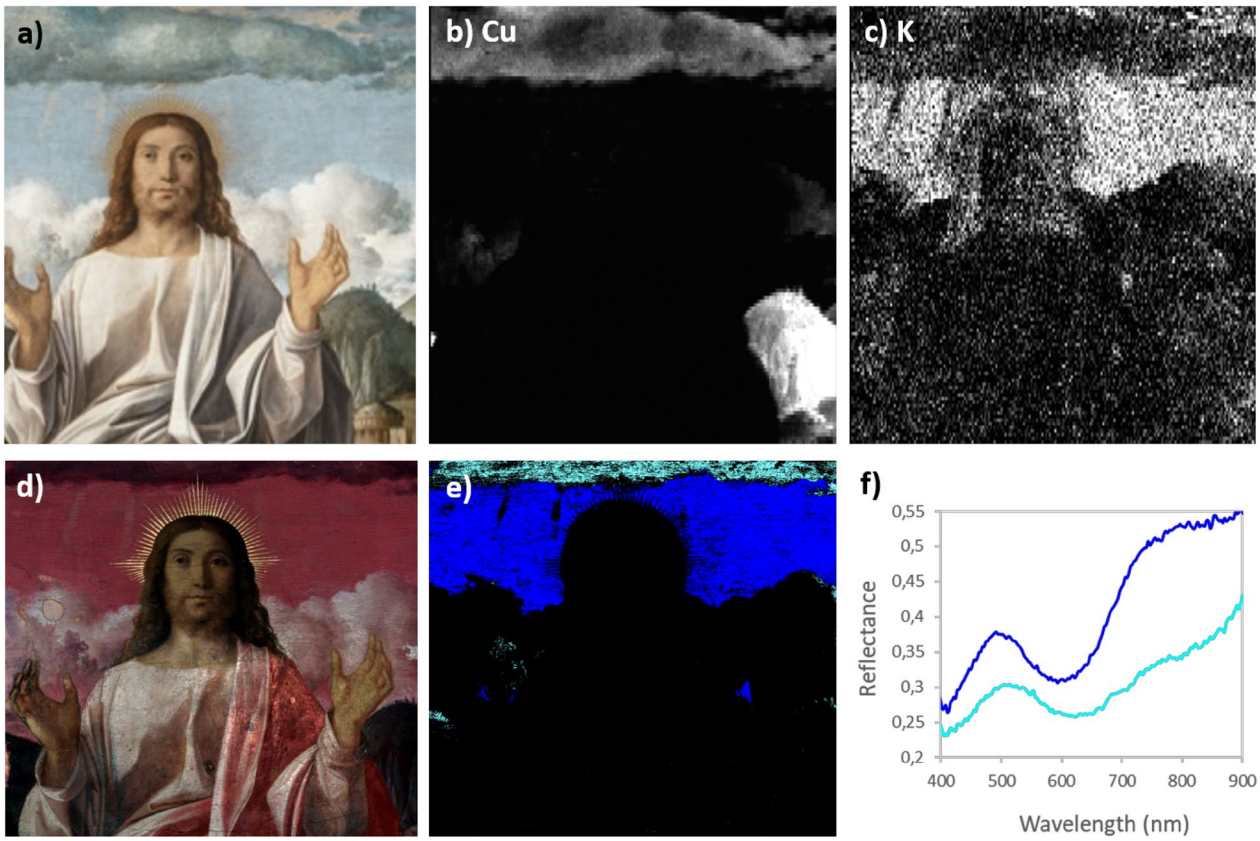

Fig. 2 **a** Detail of the *Transfiguration*; MA-XRF elemental distribution images of **b** Cu and **c** K, in the corresponding zone; **d** infrared false colour image obtained from VNIR hyperspectral data (Red 900 nm, Green 628 nm, Blue 542 nm) of a detail of the painting; **e** azurite and lapis map obtained after SAM treatment (Spectral Angle Mapper) of the VNIR hyperspectral data, from pre-defined end members shown in **f** (dark blue stands for lapis, light blue for azurite).

binder, the knowledge of Flemish works and the assimilation of the Byzantine iconographic tradition are combined with a 'modern' approach, in full awareness of the achievements of Italian Renaissance art.

We find Bellini's *Transfiguration* already referred to in 1644 and 1653 in the inventories of the Farnese palace in Rome. The work was subsequently moved to Parma, where—in about 1680—it appears in the Palazzo del Giardino, before being selected as one of the three hundred works to be exhibited in the new gallery in the Palazzo della Pilotta. It appears continuously in the Parma inventories until its transfer to Naples with Charles of Bourbon, Elisabetta Farnese's heir in 1734, together with the rest of the Farnese collection exhibited now in the Museo di Capodimonte.

Methods

The painting was investigated with VNIR hyperspectral imaging [12–15] combined to MA-XRF [16, 17], which combination have proven to be efficient tool to characterize most pigments and provide information about paint techniques [18–21].

A VNIR hyperspectral camera made by Specim (Oulu, Finland) was mounted on a rotation stage to acquire the images in push broom technique. The painting was lit with halogen lamps during the period of acquisition. The spectral range was 350 nm to 1000 nm with 212 wavelength channels (rebinned from 1200) with a spectral sampling of 2.8 nm and 1600 spatial pixels. The scan was acquired with an OL50 objective from Specim (focal length 50 mm) and with 100 ms integration time, 5 fps (frames per second) and 0.03°/s rotation speed. The dedicated ENVI software (Harris Corporation, Melbourne, Florida, USA) was used for data treatment. The data was normalized with dark and bright field images using the Specim plug-in in ENVI. The spectral angle mapper (SAM) algorithm of ENVI was used to obtain reflectance maps.

An in-house-built XRF instrument was used, featuring a Pd anode end window X-ray tube (Moxtek MAGNUM, Orem, UT) operated at 30 kV and 50 μA and a

silicon drift detector (X-123FAST SDD, Amptek, Bedford, MA) with an active area of 25 mm^2 collimated to 17 mm^2 and a nominal thickness of 500 µm. The X-ray tube was connected to the detector via a holder produced by 3D printing (fixing the angle between both to 45° for single point analysis, or 32° for imaging). As a collimator primary optic, a Pd tube of 800 µm inner diameter was used, yielding a beam size of approximately 1.2 mm. The typical working distance is 1 cm. A digital microscope (Dino-lite, AnMo Electronics Corporation, New Taipei City, Taiwan) and a laser distance measurement device (OADM20, Baumer, Frauenfeld, Switzerland) allow for measuring the position of the primary beam on the surface of the object. The system was used with manual translation stages for single-point analysis with acquisition time of 300 s. For XRF imaging the measurement head was mounted on a motorized XY stage with 20 cm travel range in both directions (M-403.8PD, PhysikInstrumente (PI) GmbH & Co. KG, Karlsruhe, Germany) with an additional manual Z translation. The motorized stage was fixed to a 3-axis manual rotation stage mounted on a photographic tripod. The instrument has been previously described elsewhere [22]. The central area was investigated using a step size of 1 mm and a dwell time per pixel 0.2 s. For the evaluation of the raw, full spectral XRF data, the PyMCA software was used [23].

Macrophotographs (Olympus OM-D E-M5 Mark II with Olympus 60 mm macro lens) of the analysed areas were also taken.

Results and discussion

The discussion will focus on Bellini's account of the manifestation of the divine on Earth, hence on the head and torso of the transfigured Christ and the surrounding area of the sky, and details related to the event. The figure of Christ is central to the meaning of the painting and our results for this area are therefore emblematic of Bellini's entire approach to the depiction of the Transfiguration.

The sky

Two different blue pigments have been identified in the sky (Fig. 2 and XRF spectra in Additional file 1: Fig. S1 and Table S1). In the azure sky against which we see Christ's head with rays of Divine light, the main chemical elements identified by XRF analyses were silicon and potassium (no cobalt) indicating the presence of lapis-lazuli (confirmed by the reflectance spectrum [24, 25] extracted from this area, Fig. 2f). In the sky beyond the clouds, which is of a darker hue, the main chemical element identified by XRF analyses was copper indicating the probable use of the blue pigment azurite, in accordance with its visible spectrum (Fig. 2f). The use of both lapis-lazuli and azurite has been found in other works by Bellini [3] but more traditionally either with underlayer of azurite followed by surface layer of lapis or at times in mixtures which is a less common occurrence [5]. The use of lapis in this particular painting may be linked to a symbolic value of these two pigments: lapis-lazuli, the most precious pigment, stands for divine. At the time lapis-lazuli originated in what is now Afghanistan, and was identified with the Garden of Eden, so that it may also have a symbolic value as well as being prized in terms of monetary worth [26, 27]. This blue area painted with lapis-lazuli is correlated with the overpowering radiance of the transfigured Christ. Azurite is used for the dark cloud that appears to envelop the onlookers and conceal the sight of God the father speaking from above, while the clear, limpid sky is painted using lapis-lazuli. It is interesting to note that in the landscape, while copper-based pigments are present elsewhere (mountains, river…), lapis-lazuli is also present in tiny blue flowers near what can be interpreted as the cross of Christ (Fig. 3).

Fig. 3 Detail of the landscape, with the pre-figuration of the Cross, and the tiny blue flowers painted with 'celestial' lapis-lazuli

The figure of Christ

Specific composition of the halo

The rays in the halo around the head of Christ were represented with gold whereas lead tin yellow has been used for the rays of the sun in the sky (Fig. 4). The difference in the nature of the rays is thus reflected in the materials

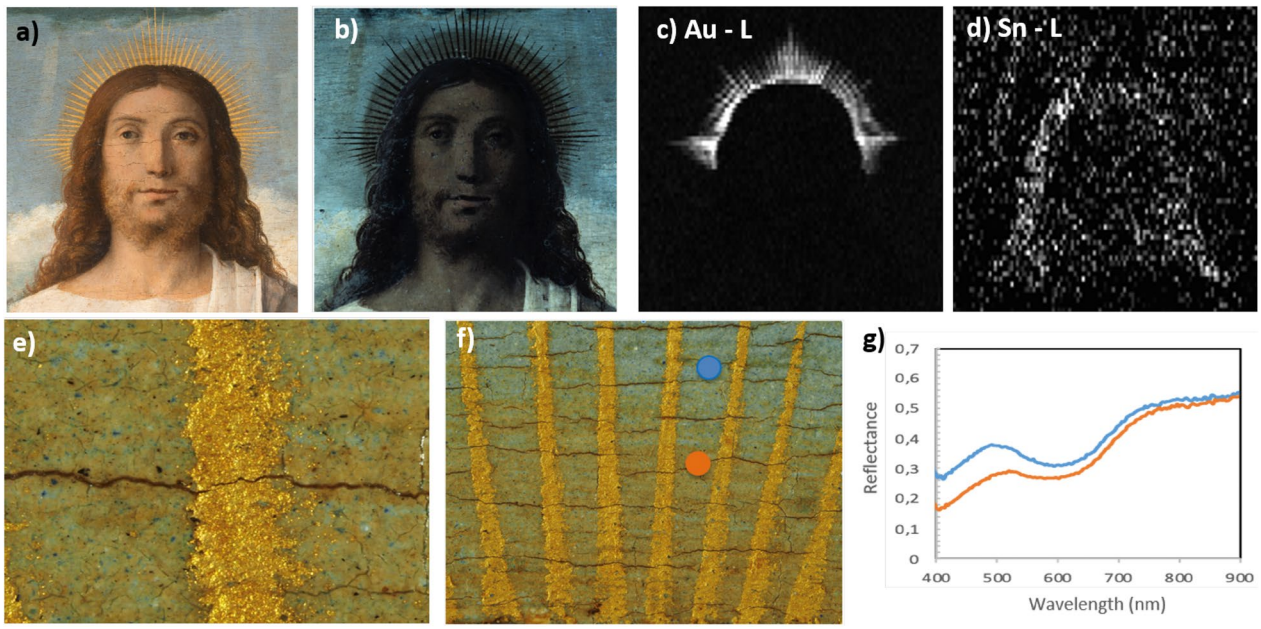

Fig. 4 Study of the halo **a** Detail of the Transfiguration centered on the face of Christ; **b** UV fluorescence photographof the corresponding zone; MA-XRF elemental distribution images of: **c** Au (L lines) and **d** Sn (L lines), in the corresponding zone; **e** macro-photograph of a ray of the halo showing the shell-gold; **f** macrophotograph of the halo and **g** reflectance spectra of the two points indicated in **f**)

used to represent them: both are manifestations of 'light', but the rays emitted by the figure of Christ are of a divine nature, as symbolized by the gold. The light emitted by the sun is, in contrast, of a terrestrial nature.

It is also particularly interesting to note the presence of a broad, dark golden yellow halo (particularly visible in the UV photograph, Fig. 4b below) surrounding Christ's head, beneath the golden rays. We then compared the reflectance spectrum of this yellow halo to the one of the surrounding sky (Fig. 4f, g below). The halo induces a significant absorption in the blue part of the reflectance spectrum leaving the rest of the spectrum unchanged. In the same way as an old discoloured varnish, it acts as a yellow filter [28]. This suggests, as does observation of the paint surface, that this halo is an organic layer painted over the sky. However, the warm hue of this layer is not simply due to ageing, but deliberate, in that both particles of Fe and Hg (that is an earth pigment and vermilion) have been added (visible in macrophotographs and confirmed by XRF). A similar technique was used by Bellini in the early *Blood of the Redeemer* in the National Gallery (London) [6, 7] (p. 39) in conjunction again with shell-gold, in the latter painting used in the chalice as well as the halo.[3]

[3] « The angle's chalice has brown base colour with shell gold detailing i.e. not mordant gilding. Brown shows in the Fe XRF map.» (Unpublished report, Scientific Dept. National Gallery, London. Accessed courtesy of ARCHLAB-IPERION).

Modelling of flesh tones and hair

When we compare the X-radiograph and the complementary Pb XRF map of Christ's head with what we see in the painting (Fig. 5), it becomes clear that the current outline gives Christ a broader head compared to the original more elongated one. This broader shape is more in keeping with a powerful figure of Christ resurrected and transfigured, rather than the Christ of Sorrows. The image also suggests a change in the position of the Christ's eyes and/or of head. Christ may originally have had his eyes turned towards the heavens or towards Moses, as in the early Bellini's Correr *Transfiguration* (Fig. 6a), rather than fixed outside of the picture plane towards the onlooker.[4] This is a theologically significant change: in the later Capodimonte *Transfiguration,* Christ is looking towards us. We have observed above how Christ's pose is that found in the Byzantine tradition, but it is possible to be more precise. Christ is depicted as the shepherd of his flock, symbolized also by the presence of the sheep in the landscape on the left, on the hill. On the other side, to the right of the figure of Christ, we see the tower of St Apollinare in Classe in Ravenna in

[4] The *Transfiguration* in the Correr Museum in Venice can be dated to around 1460, a time when he was strongly influenced by his contacts with Mantegna. It is significant that IR and X-ray investigations showed that also in the first setting of the Capodimonte *Transfiguration* Elijah and Moses had their eyes open turned towards Christ, as in the older Correr depiction [3, pp. 352–353].

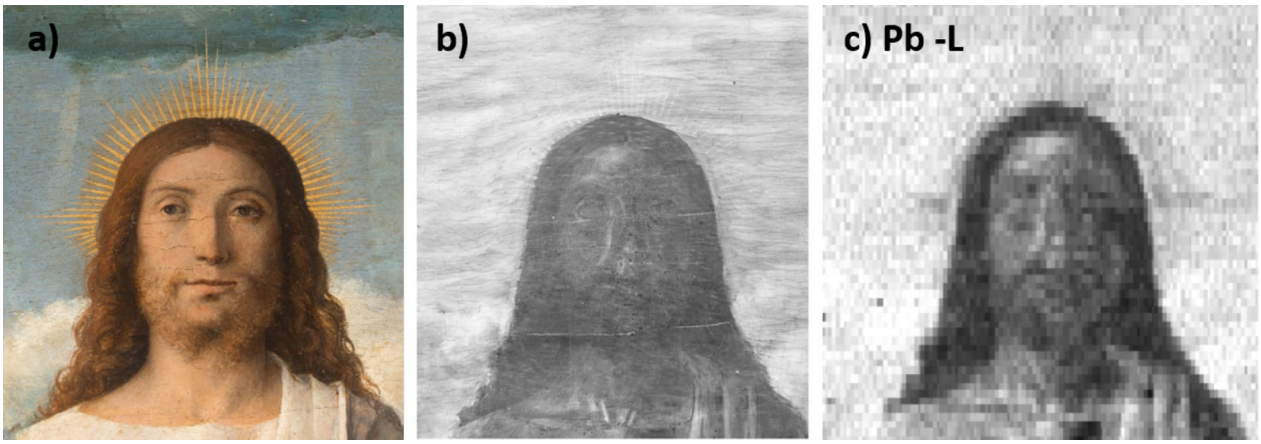

Fig. 5 **a** Detail of the Transfiguration centered on the face of Christ; **b** X-radiograph and c MA-XRF elemental distribution image of Pb (L lines).

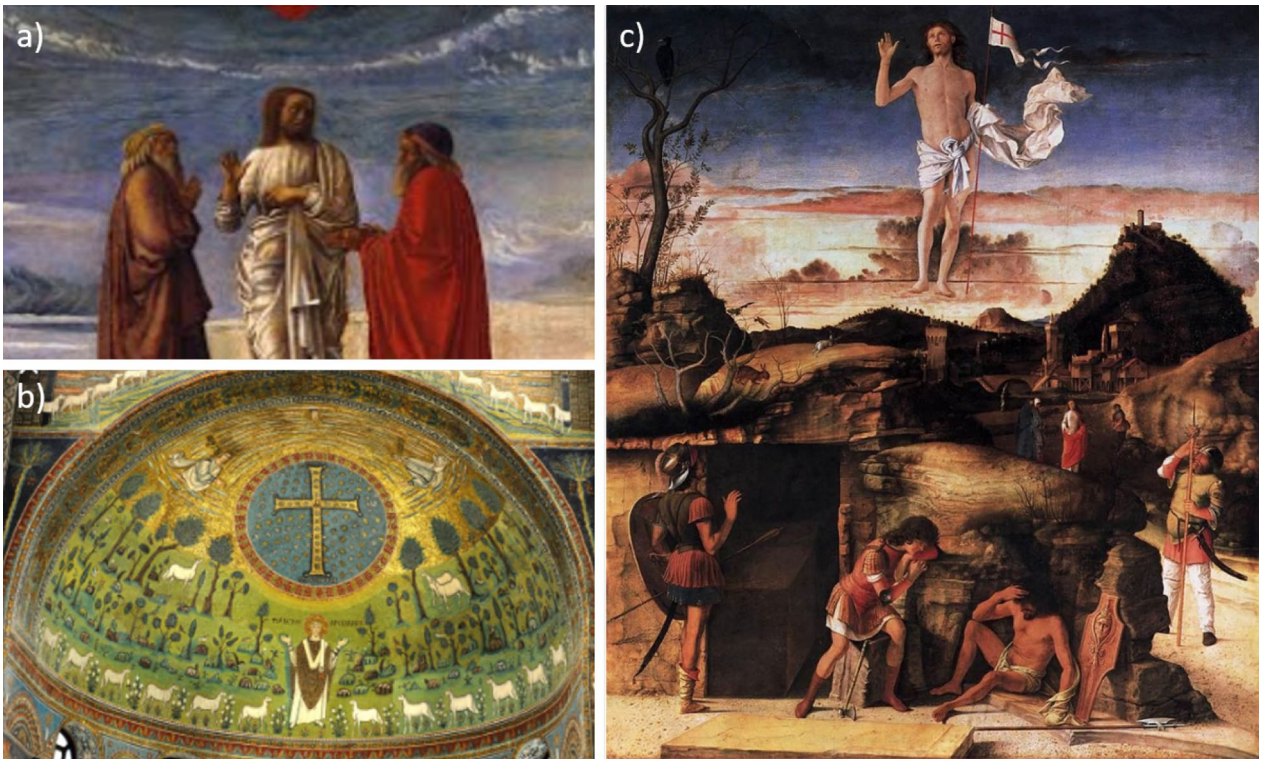

Fig. 6 **a** Detail of the early *Transfiguration* (1454–1460) Museo Correr, Venice (Wiki commons); **b** *Transfiguration* mosaic in Sant'Apollinare in Classe, Ravenna; **c** Giovanni Bellini *Resurrection* (1475–1479), Gemäldegalerie, Berlin (Wiki commons).

which church is found one of the most magnificent and beautiful mosaic symbolic representations of the Transfiguration of Christ (Fig. 6b). In the mosaic Christ is represented by the Cross, the three apostles by three sheeps, while the figure of St Apollinaris is depicted as the good shepherd, in an orating pose, with the flock of sheep on his right and left. Comparing these different images (Fig. 5) suggests that the figure of the transfigured Christ at first was perhaps closer to the Christ painted by Bellini in the Correr *Transfiguration* before becoming closer to that of the orating St Apollinaris in the Ravenna mosaic.

As is customary, both vermilion (characterized by the presence of Hg) and an earth pigment have been both used for faces and hands (Fig. 7 and Additional file 1: Fig. S2). Calcium is also present in greater quantities in areas of shadow, in such cases it is usually linked to the

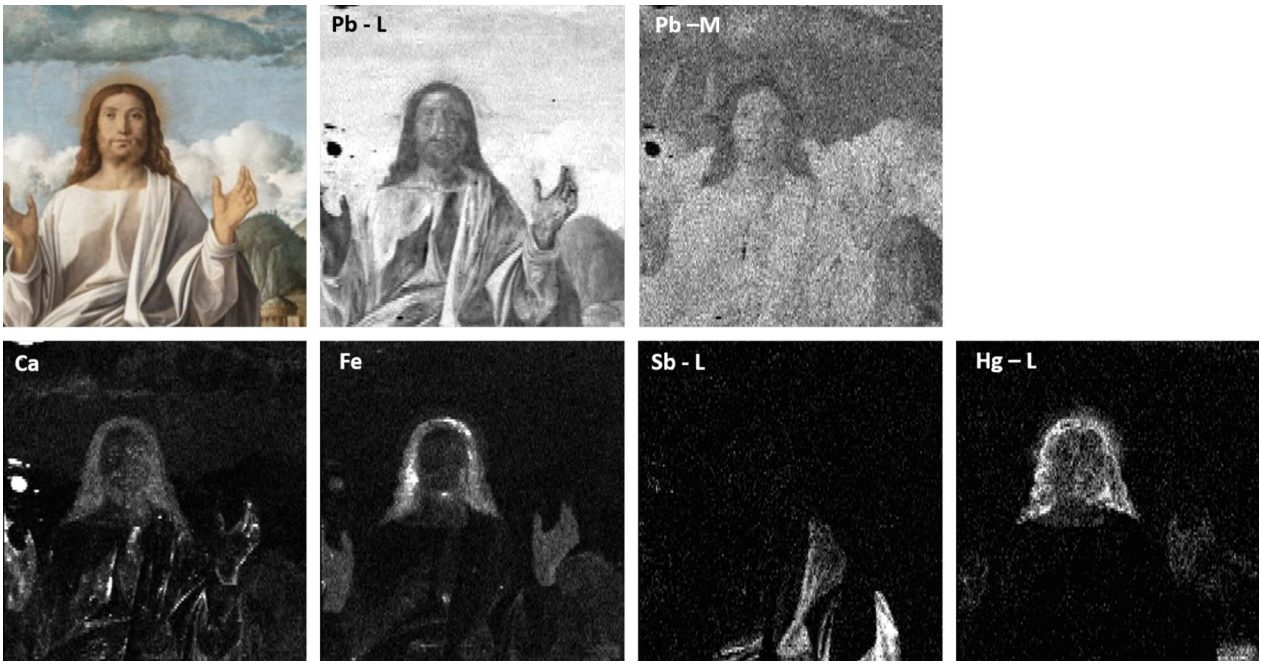

Fig. 7 Selection of MA-XRF elemental distribution images

presence of earth pigments or bone black; however here, it does not follow the same variations as iron, and there is no phosphorus. The same kind of calcium variations seems to be present in Christ's tunic. These variations might be due to the absorption of lead white: thick layers of lead white in the lights will absorb the calcium signal from the gesso ground, in contrast to the nearly lead-free layers of the shadows.

The brown colour of the hair is obtained using a mixture of pigments, rather than a single pigment—earth, vermilion and probably lead tin yellow (the presence of tin being difficult to assess in low concentrations, given the calcium content). This use of a mixed brown for hair—the tonalities of which can be manipulated in accordance with the fall of light and shadow by varying the proportions of individual pigments—is also found in the works of Raphael's father, Giovanni Santi [29] and the early Raphael,[5] for example [30], as well as being a technique used by Bellini from his earliest works.[6]

Modelling light and shadow/warm and cool tonalities in the draperies

In Christ's pale blue/grey cloak, the XRF spectra (Additional file 1: Fig. S3) indicated the presence of antimony (Sb), characteristic element of the dark grey pigment stibnite (Sb_2S_3), a pigment which has been found in other works painted in this period [31, 32]. This would appear to be the earliest work in which the pigment has been to date identified. Marika Spring ([19], p. 209) rightly observes that although these metallic pigments have luster when seen under the microscope, this is not the case when observed on the picture surface. For comparison with Bellini, she observes "In the *Virgin and Child with four Saints* (NG 3091) by Bonsignori stibnite was used for the grey shadows of the white drapery of the saint on the right and for the dark grey beard of the elderly saint" ([32], p. 102]). In Bellini's *Transfiguration* stibnite produces the cold metallic grey tones that we see in the shadows of Christ's cloak.

In contrast to the cloak with its cool tonalities, the warm white of the tunic—under magnification—shows not only the presence of red lake particles imparting the rosiness, but also a few blue particles, thus bridging and unifying the two draperies. Paul Hills, examining Bellini's *Resurrection* (thought to have been painted in these same years, Fig. 6c) from the Gemäldegalerie, Berlin during the exhibition at the Quirinale in 2008, also noted the difference in the whites between the loin cloth and the winding sheet (the shroud), the former a bluer tonality, and

[5] For instance, one of several examples, in the early *Saint Sebastian* in the Accademia Carrara in Bergamo, see [30] p.44.

[6] For instance in the National Gallery, London's *Blood of the Redeemer,* again just one of several examples, in the hair of both Christ and the angel, for which the XRF maps indicated the presence of Hg and Fe and Sn (lead–tin yellow). Unpublished report as in note 2.

the other pinker[7] [33]. Other works by Bellini show his interest in capturing exactly the desired tonality of white, either to be true to the light, or to the symbolic message of the painting. In the *Madonna of the Meadow* in the National Gallery for instance the white of the Virgin's veil—both in lights and shadows—is tinged with green, particles of verdigris are visible under magnification.[8] It is again Paul Hills, who makes the following observations which, although directed to the role of white in a later altarpiece by Bellini, are equally valid for his Capodimonte Transfiguration: « In this spatial play of colour the orchestration of whites plays a crucial part: even if subtleties have been lost due to changes over time, we can still appreciate Bellini's strategy in deploying a range of near-whites shifting between warm and cool. (….) what is most distant—the luminosity of the sky with its modulation of blue, warm grey, and palest apricot—is associated with what is most near. So the light of heaven is admitted through the intercessory saints, and through the almost secret, luminous presence of the pale flesh of Christ, into the very space of the church, San Giovanni Crisostomo» ([1] p. 194). The artist achieves with his handling of pigments the radiance of the gold of mosaics and the luminosity, so central to the depiction of the divine scene—"His face shone like the sun, and his clothes became as white as the light" (Matthew 17: 2, Bible, new international version).

From evidence in the painting it is possible to go further in the comparison with the mosaic representation in Ravenna: in the mosaic, Christ is represented as a jewelled, metallic cross. Bellini in his painting has not only indicated the church, but has included the flock of sheep (Christ is the living—human—shepherd) and the modelling of Christ's cloak with this unusual metallic pigment can be interpreted as a material allusion to his Divine as well as human nature (as in the mosaic). Such a symbolic interpretation can also be extended, as we have observed above, to the tree stump with its three 'nails' in the bottom left of the painting, alluding to the Cross. Such symbolic pictorial language was an integral part of the medieval tradition of representation, which continued and fed the arts well into the Renaissance period and beyond.

Conclusion

Giovanni Bellini's Capodimonte *Transfiguration* stands at the crossroads between the Byzantine and medieval traditions and the modern age*:* the results show both continuity with the Flemish technique (in particular in the rendering of the natural light over the figures and, moreover, the landscape) and with that already described in works by Bellini that precede this work (shell gold and tinted organic layers already found in early work). On the contrary, innovative features can be highlighted such as the earliest example to date of the use of stibnite*.* The choice of different pigments (gold vs lead tin yellow, lapis vs azurite) appears to be linked to their symbolic value in order to represent the divine event but also to modulate colour as in nature. Bellini takes from tradition the hieratic pose of the praying Christ, the fixity of his gaze, the very distribution of the figures in space, but everything is set in nature, everything is rendered with verisimilitude. The description of the light in this work by art historians is confirmed by material analysis, in particular thanks to chemical imaging that allows the handling of the material to be visualized. The artist achieves with his handling of pigments the radiance of the gold of mosaics and gold-backgrounds transmuted into modulations of light belonging to the natural world.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40494-023-01001-7.

Additional file 1: Table S1. List of the main pigments discussed in the text, corresponding to the central area of the figure of Christ. **Figure S1.** XRF spectra from the sky: **a** lower part; **b** from the clouds. **Figure S2.** XRF spectra from the face: light area (black) and shadow of the nose (red). **Figure S3.** XRF spectra from **a** the grey cloa and **b** white tunic.

Acknowledgements
The authors are grateful to Marika Spring, Jill Dunkerton, David Peggie and Rachel Billinge for fruitful discussions and access to the archival material in the Scientific Department, National Gallery, London.

Author contributions
Funding, Acquisition and supervision, LV and PW; XRF and hyperspectral analyses: LV, MR and PW, Resources and archive information, HG, AC, AR and CS; Writing, original draft and review, HG and LV. All authors read and approved the final manuscript.

Funding
This research was funded by the French State managed by the National Research Agency under the program Future Investments bearing the reference ANR-16-LCV1-0005-01 (program Labcom Lab4Art) and ANR-21-CE29-0014-01, contract number [236235] (program JCJC SWIP).

Data Availability
Data available on request due to restrictions eg privacy or ethical. The data presented in this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

[7] « Examining Bellini's *Resurrection* in the exhibition in the Scuderie del Quirinale in Rome in 2008, it was evident that the loincloth is shaded with a slightly bluer tint than the fluttering cloth to the right» [33, Note 22, p.76].

[8] National Gallery report, thanks to ARCHLAB.

Competing interests
The authors declare that they have no competing interests.

Received: 13 April 2023 Accepted: 17 July 2023
Published online: 04 August 2023

References

1. Hills P. Bellini's Colour in The Cambridge Companion to Giovanni Bellini. Ed. Peter Humphrey, Cambridge 2008, p.191.
2. Daffra E. Giovanni Bellini. La nascita della pittura devozionale umanistica; gli studi, catalogo mostra Milano, Pinacoteca di Brera, Milan; 2014. (in Italian)
3. Cerasuolo A. Giovanni Bellini, La Trasfigurazione. In: Bertelli C, Bonsanti G, editors. Restituzioni, exhibition catalogue (Torino, Reggia di Venaria, 28 marzo - 16 settembre 2018). Venezia: Marsilio; 2018. p.350–7. (in Italian)
4. Cerasuolo A, Rullo A. Giovanni Bellini, Trasfigurazione, In : Bertelli C, Bonsanti G, Di Francesco C, editors. Restituzioni: tesori d'arte restaurati. La fragilità e la forza, diciannovesima edizione. Milano : Skira Editore ; 2022. p. 326–37. (in Italian)
5. Caglio S, Frezzato F, Poldi G. Pigmenti, leganti, strati: osservazioni analitiche sulla tecnica pittorica del 'Battesimo di Cristo' In: Bellini a Vicenza, Pala di Santa Corona, 2007. (in Italian)
6. Braham A, Wyld M, Plesters J. Bellini's "The Blood of the Redeemer'. Nat Gallery Tech Bull. 1978;2:11–24.
7. Dunkerton J, Spring M. Giovanni Bellini's painting technique. Nat Gallery Tech Bull. 2018;39.
8. Bonizzoni L, Caglio S, Galli A, et al. A non invasive method to detect stratigraphy, thicknesses and pigment concentration of pictorial multilayers based on EDXRF and vis-RS: in situ applications. Appl Phys A. 2008;92:203–10.
9. Poldi G, Villa CF. A new examination of Giovanni Bellini's 'Pesaro Altarpiece': recent findings and comparisons with other works by Bellini. In: Spring M, editor. Studying Old Master Paintings—Technology and Practice, National Gallery Technical Bulletin 30th Anniversary Conference Postprints. London Archetype; 2011. p.28–36.
10. Goffen R, Nepi Scirè G. editors. Il colore ritrovato, Bellini a Venezia. Milano: Electa; 2000. (in Italian)
11. Frezzato F. Aspetti della techné belliniana tra il 1460 e il 1470 rivelati dalle analisi microstratigrafiche sulla Pietà, in the catalogue of the exhibition Giovanni Bellini. La nascita della pittura devozionale umanistica. Pinacoteca di Brera, 9th April, Milan, p.105–8. (in Italian)
12. Catelli E, Li Z, Sciutto G, Oliveri P, Prati S, Occhipinti M, Tocchio A, Alberti R, Frizzi T, Malegori C, Mazzeo R. Towards the non-destructive analysis of multilayered samples: a novel XRF-VNIR-SWIR hyperspectral imaging system combined with multiblock data processing. Anal Chim Acta. 2023;1239: 340710.
13. Delaney JK, Zeibel JG, Thoury M, Littleton R, Palmer M, Morales KM, de la Rie ER, Hoenigswald A. Visible and infrared imaging spectroscopy of Picasso's Harlequin musician: mapping and identification of artist materials in situ. App Spectr. 2010;64(6):584–94.
14. Cucci C, Delaney JK, Picollo M. Reflectance hyperspectral imaging for investigation of works of art: old master paintings and illuminated manuscripts. Acc Chem Res. 2016;49:2070–9.
15. de Viguerie L, Oriols Pladevall N, Lotz H, Freni V, Fauquet N, Mestre M, Walter P, Verdaguer M. Mapping pigments and binders in 15th century gothic altarpieces using a combination of visible and near infrared hyperspectral imaging. Microchem J. 2020;155: 104674.
16. Ricciardi P, Legrand S, Bertolotti G, Janssens K. Macro X-ray fluorescence (MA-XRF) scanning of illuminated manuscript fragments: potentialities and challenges. Microchem J. 2016;124:785–91.
17. Alfeld M, Vaz Pedroso J, van Eikema HM, Van der Snickt G, Tauber G, Blaas J, Haschke M, Erler K, Dik J, Janssens K. A mobile instrument for in situ scanning macro-XRF investigation of historical paintings. J Anal At Spectrom. 2013;28:760–7.
18. Dooley KA, Conover DM, Glinsman LD, Delaney JK. Complementary standoff chemical imaging to map and identify artist materials in an early italian renaissance panel painting. Angew Chem Int Ed. 2014;53:13775–9.
19. Alfeld M, de Viguerie L. Recent developments in spectroscopic imaging techniques for historical paintings - A review. Spectrochim Acta Part B. 2017;136:81–105.
20. de Viguerie L, Rochut S, Alfeld M, Walter P, Astier S, Gontero V, Boulch F. XRF and reflectance hyperspectral imaging on a 15th-century illuminated manuscript: combining imaging and quantitative analysis to understand the artist's technique. Heritage Sci. 2018;6(1):11.
21. Brocchieri J, de Viguerie L, Sabbarese C, Boyer M. Combination of non-invasive imaging techniques to characterize pigments in Buddhist thangka paintings. X-ray Spectrom. 2020;1:12.
22. Alfeld M, Mulliez M, Martinez Ph, Cain K, Jockey Ph, Walter Ph. The eye of the medusa: XRF imaging reveals unknown traces of antique polychromy. Anal Chem. 2017;89(3):1493–500.
23. Solé VA, Papillon E, Cotte M, Walter Ph, Susini J. A multiplatform code for the analysis of energy-dispersive X-ray fluorescence spectra. Spectrochim Acta B. 2007;62:63–8.
24. Aceto M, Agostino A, Fenoglio G, Idone A, Gulmini M, Picollo M, Ricciardi P, Delaney JK. Characterisation of colourants on illuminated manuscripts by portable fibre optic UV-visible-NIR reflectance spectrophotometry. Anal Methods. 2014;6:1488.
25. Cosentino A. FORS spectral database of historical pigments in different binders. E-cons J 2014;2: 53–65.
26. Kirby J. The price of quality: Factors in influencing the cost of pigments during the Renaissance. In: Revaluing Renaissance Art. (eds G. Neher and R. Shepherd) Aldershot. 2000; 19–42.
27. Plesters J. Artist's pigments: a handbook of their history and characteristics, vol. 2. Washington: National Gallery of Art; 1993. p.37–65.
28. Liang H. Advances in multispectral and hyperspectral imaging for archaeology and art conservation. Appl Phys A. 2012;106:309–23.
29. Amadori ML, Poldi G. La tecnica pittorica di Giovanni Santi in Giovanni Santi (Ed. Maria Rosaria Valazzi), Cinsello Balsamo, Milano; 2018. (in Italian)
30. Borghese P, Frezzato F, Fumagalli P, Ghisalberti N. Il 'San Sebastiano' di Raffaello restaurato—un modello di conoscenza. Kermes. 2014;93:35–50. (in Italian)
31. Ferretti M, Guidi G, Moioli P, Scafè R, Seccaroni C. The presence of antimony in some grey colours of three paintings by Correggio. Stud Conserv. 1991;36:235–9.
32. Spring M, Grout R, White R. 'Black earths': a study of unusual black and dark grey pigments used by artists in the sixteenth century. Natl Gallery Tech Bul. 2003;24:96–114.
33. Hills P. Vesting the body of Christ in examining Giovanni Bellini: an art 'More human and more divine'. Ed. Wilson C. Brepols 2015, p. 61–76.

Publisher's Note